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Research of Full Digit Single-phase Inversion Power Supply Based on DSP

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Abstract

With the increasing need of high quality power supply resulting from the use of electric appliances day by day, research on high-performance PWM inverter is gaining more and more attention. In order to improve the waveform quality of the inverter, a design of single-phase inverter system based on modified competitive control was put forward. Due to the numerous advantages of digit control, it is gradually replacing simulation control. At the end of this thesis, TMS320F2812 is adopted to realize the scheme of digit close-cycle control, system hardware and software are designed, and an experiment is conducted, which proves the good waveform quality and high precision of inverter system with repetitive compensation and low aberration rate of output voltage waveform. What’s more, this system has both good stability and fast response speed.

Keywords: Inverter, Digit Control, TMS320F2812

1. Introduction

Research on high-performance PWM inverter is gaining more and more popularity. SPWM inverter is an inverter most widely used at present. As a high-performance inverter, except that it must feature such basic elements as small volume, light weight and good electromagnetic compatibility, it must also possess the capability of outputting high quality voltage waveform, enough output power and high stability [1]. Thus, people have come up with various control methods to enhance the quality of its output waveform these years, such as PID control, repetitive control, dual-loop feedback control, triple-loop control, deadbeat control and so on. Among all these the most widely used are the schemes of voltage-current dual-loop control and repetitive control. Dual-loop control is characterized by the simple design of the controller, the low distortion rate of output voltage waveform and the fast dynamic response speed, but it has the following disadvantage: it can not eliminate static error when it traces swiftly changing sinusoidal

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wave because it employs PI modulation. On the other hand, repetitive control is a new-type control strategy on the basis of internal model principle, which has good and stable output property and excellent robustness when it comes to the tracking and restraint of periodic extra stimulating signals. This thesis constructs the mathematical model of single-phase inverter, analyzes the open-loop inverter, brings forward a control scheme combining dual-loop control and repetitive control after analyzing the characteristics of dual-loop control, and finally builds a 50Hz single-phase inverter experiment system taking TMS320LF2407 as the rockchip. The experiment is carried out and thereby the result of it proves the correctness of the built module.

2. The Mathematical Model of Single-phase Full Bridge Inverter

The main circuit of the single-phase inverter is shown in figure 2[2]. In the figure, T_1, T_2, T_3, T_4 are power switching valves; filter inductance L and filter capacitance C form the low-pass filter; R_r is the comprehensive equivalent series resistance taking into account of filter inductance L, and the comprehensive equivalent resistance of different damping factors in the inverter such as hole effect, switching valve breakover voltage drop and line resistance and etc.; U_d is the direct-current (DC) generatrix voltage; u_1 is the inverter bridge output voltage; u_o is the inverter output voltage; i_1 is the current flowing through the filter inductance and i_o represents the load current.

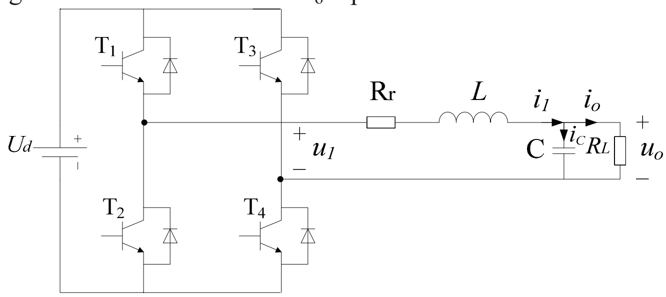


Fig. 1. Illustrative Diagram of the Main Circuit of Single-phase Full Bridge

Under the modulation of SPWM and if the dead zone is not considered, the control signals of T_1 and T_4 are the same, the control signals of T_2 and T_3 are the same, the signals of T_1 and T_2 are complementary, and the amplitude output by the inverter bridge is impulse voltage U_d or-U_d and if the switching variable S_i is used to express on-off control:

S_i =1 represents T_1 and T_4 breakover, T_2 and T_3 shut off

S_i =0 represents T_2 and T_3 breakover, T_1 and T_4 shut off

then the inverter output voltage is a couple polarity impulse voltages, which can be expressed as such:

$$u_1 = U_d (2S_i - 1) \tag{1}$$

When the load voltage is considered as the disturbance quantity, then the inverted power supply outputs filter, and then we can take output voltage u_o and inductance voltage i_1 as state variables, u_1 and i_o as the input quantity and disturbance quantity respectively, and output voltage u_o as the output quantity, thus we can gain the filter linear two-input and single-input state space mode output by the inverter, whose state equation under the continual domain is like this:

$$\begin{cases} \dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}u_1 + \mathbf{W}i_0 \\ \mathbf{y} = \mathbf{C}\mathbf{x} \end{cases} \tag{2}$$

In the formula: $\mathbf{x}=\begin{bmatrix} u_0 \\ i_1 \end{bmatrix}$, $\mathbf{A}=\begin{bmatrix} 0 & \frac{1}{C} \\ -\frac{1}{L} & -\frac{r}{L} \end{bmatrix}$, $\mathbf{B}=\begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix}$, $\mathbf{W}=\begin{bmatrix} -\frac{1}{C} \\ 0 \end{bmatrix}$, $\mathbf{C}=\begin{bmatrix} 1 & 0 \end{bmatrix}$

If we value u_0 as the output and u_1 as the input, and according to the space state average model we can deduce the transfer function of the inverter as such:

$$P(s)=\frac{\frac{1}{sC}//R_L}{sL+R_r+(\frac{1}{sC}//R_r)}=\frac{1}{s^2LC+s(\frac{L}{R_r}+R_rC)+1+\frac{R_r}{R_L}} \tag{3}$$

When it is no-load, $R_L \to \infty$, we write formula (1) in a standard form, then:

$$P(s)=\frac{\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2} \tag{4}$$

In the formula: $\omega_n = 1/\sqrt{LC}$, $\xi=\frac{R_r}{2}\sqrt{\frac{C}{L}}$, then we value filter inductance and capacitance respectively as: L=1.45mH，C=60μF, and inductance equivalent resistance as R_r=0.3Ω, then:

$$P(s)=\frac{3032.5^2}{s^2+166.7s+3032.5^2} \tag{5}$$

From formula (3), when the system is no-load, transfer function is a system with very light damping, which is bad for the stability of the system, therefore, when we choose a control strategy, we should first raise the relative stability of the system and perfect the light damping of the system.

3. System Control Strategy

3.1 Basic Principles of Repetitive Control

Repetitive control is an effective method of modifying the stability of inverted power supply.The basic concept of repetitive control derives from the internal model principle in the control theory. The basic element of the internal model principle is to implant the dynamic model which acts on the external signals of the system into the controller to constitute a feedback control system with high precision [3,4]. The mathematical model of this external signal is the so-called "internal-model". It is not difficult to acquire the periodic disturbing signals of the controlled system. Only if the forward path of a feedback system includes integral element 1/s, then this system can conduct static tracking in response to step-index commands and meanwhile it can counteract all the effect on steady state output from step-index disturbances after they act on the integral element. Repetitive control theory utilizes the internal model principle and set up an internal model with the same period as the external signal in the steady close-cycle system, thus making the steady tracking of the external period reference signal possible.

The inverter waveform control system is a servosystem whose command changes in the form of sinusoidal function. The disturbance of this system is equivalent to the overlap of multi harmonic disturbance which appears repeatedly in the exactly same waveform during each fundamental period. Hence we can use the repetitive control theory based on the internal model principle to carry out waveform control on the inverter. The repetitive control based on the internal model principle makes use of "repetitive signal generator" internal model, whose S domain formula is: $G_m(s) = 1/(1-e^{-Ls})$. In this formula, L is the inverter output fundamental period. The output of this internal model is the gradual accumulation of input signals during each period and the aberration rate is low in steady state.

Resulting from the digit development trend of the control system and the difficulty of using simulation methods in the pure delay section, in practice repetitive control is all realized digitally. The discrete form of the repetitive signal generator is such:

$$G(z) = \frac{1}{1-z^{-N}} \tag{4}$$

In the formula: N is the sampling times during each fundamental period. The internal model structure of the improved repetitive controller is shown in figure 2.

In the figure, $Q_{(z)}$ is the auxiliary compensation section, which can be chosen as the filter.

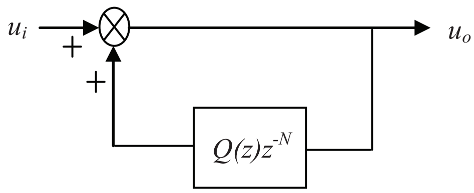


Fig. 2.The Internal Model Structure of the Improved Repetitive Controller

3.2 Design of the Repetitive Controller

Figure 3 is the inverted power supply control scheme based on repetitive control. In the figure, the improved repetitive control internal model structure is applied and the design of the repetitive controller internal model mainly targets the choice of Q(z), which should take into consideration of the stability and astringency of the system. Generally speaking, Q(z) can be a low-pass filter, and can also be simply valued as a constant approximately less than 1, so as to weaken the effect of accumulation. Nevertheless, it is more complicated to use low-pass filter, so we value Q(z)=0.98[5] according to our experience.. Compensator S(z) is used to change the property of the controlled target to ensure the stability of the system, and therefore we usually choose second order filter; phase compensation section z^k (k is lead step length), which is applied in S(z) and the general phase delay brought about by the controlled target, and which makes the controller send out correcting values k beats ahead in the next period according to the error information of the last period; scale coefficient K_r is used to determine the amplitude of the correcting value at the end, whose value $0 \le K_r \le 1$; P(z) is the transfer function of the controlled target.

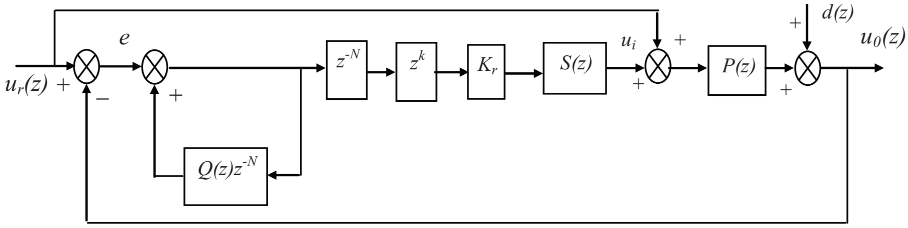


Fig. 3. The Diagram of Inverter Repetitive Control

The design target of this system is shown in figure (3). If we value switching frequency.20kHz, then the discrete model is:

$$P(z) = \frac{0.5z + 0.48}{z^2 - 0.902z + 0.9011} \qquad (5)$$

Because the resonance peak value of the no-load inverter is too high, it is necessary to design S(z) to eliminate it. Here compensator S(z) adopts second order filter. Moreover, we will descend the resonance peak value to 0 due to the high resonance peak value and combine the analysis of the software frequency domain , and choose S(z) to be:

$$S(z) = \frac{0.0699z + 0.0522}{z^2 - 1.398z + 0.516} \qquad (6)$$

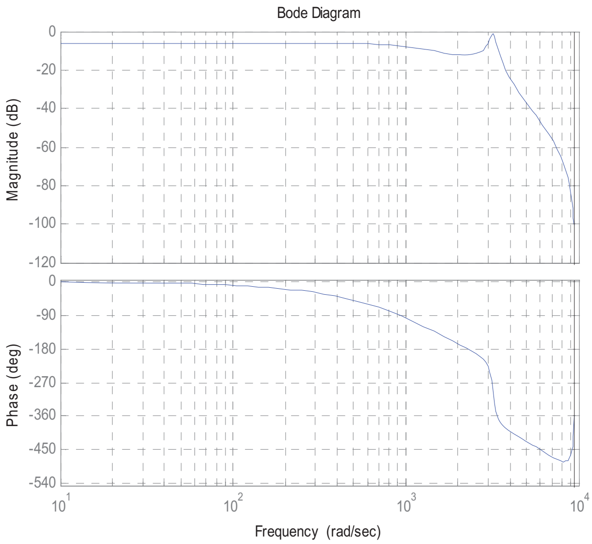


Fig. 4. Frequency Characteristic Curve of the Inverter After Repetitive Control

Coefficient Kr is the gain of repetitive controller and its value needs to be less than 1 because the resonance peak value should be less than 1 after the compensation of the repetitive control second order filter, thus we value Kr=0.6. Figure 4 is the frequency characteristic curve of the inverter after repetitive control is added. We can see the low frequency range resonance peak value of the inverter amplitude-frequency characteristic curve has sharply reduced to around 0dB through correction compensation and the system is dropping at -80dB/dec after corner frequency. Thus high frequency disturbance signals can be effectively restrained and the phase delay arisen by S(z)P(z) can be better compensated.

4. The Composition of the System and the Experiment

Based on the above analysis, the experiment system is built which uses TMS320F2812 as the rockchip. The structure of the system is shown as in figure 5. The main electric circuit is made up of rectification, filtration and inverter units. Single-phase alternating current (AC) inputs voltage and then provides to the inverter through rectification. Under the effect of the driving signal, the inverter transfer direct current (DC) to alternating current (AC), and then supply to the load through filtration. The inverter adopts IGBT. The sampling of the output voltage, filtration capacitive current, inductive current and temperature will be sent to and dealt with by DSP, which outputs the modified SPWM control signal according to the control algorithm, thus making the system output stable and high quality sine alternating current[6].

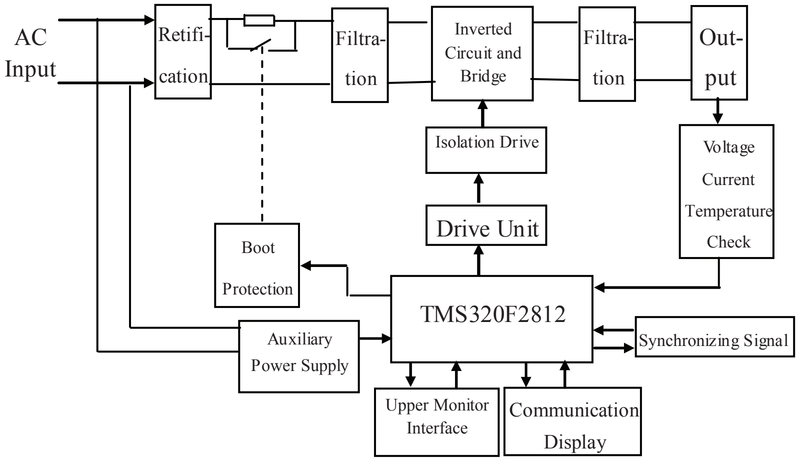
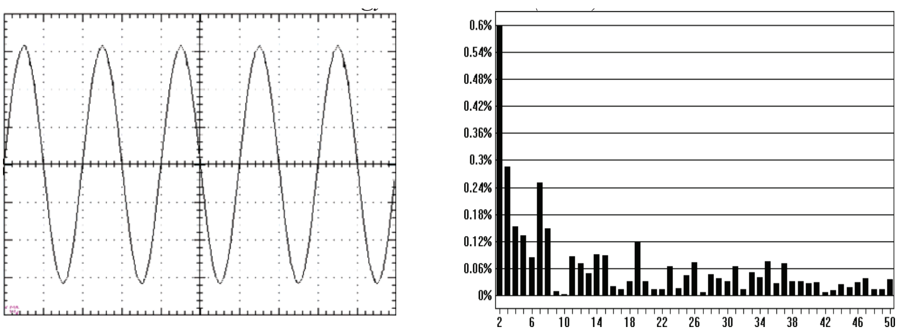


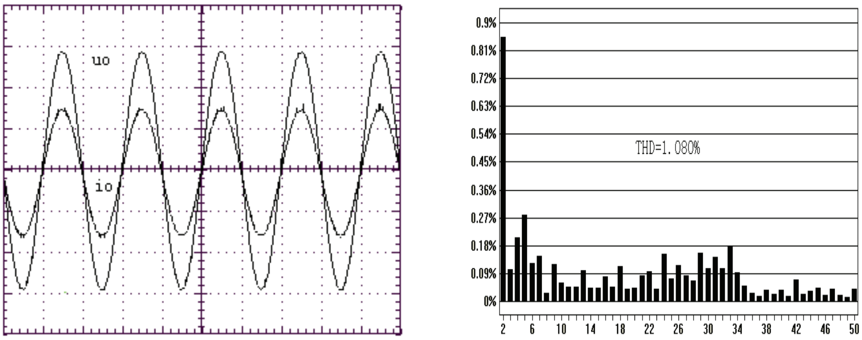
Fig. 5.The Structure of the Inverted Power Supply System

The system takes TMS320LF2812 as the rockchip, mainly realizes repetitive control algorithm, outputs PWM control impulse, samples at regular time and implements A/D transfer of the sampling values of voltage, current and temperature and protects the system in a comprehensive way. System software consists of the main program and the interrupt servicing program, with the former fulfilling the system initialization and the setting of the interrupt servicing and the latter carrying out the section in great need of real-time.



(50V/div, 5ms/div)

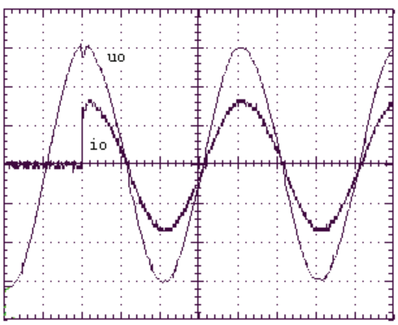
Fig. 6. Waveform and Harmonic Wave Analyses of the No-load Output Voltage



(100V/div, 50A/div, 10ms/div)

Fig. 7. Waveform and Harmonic Wave Analyses of the Output Voltage and Current with Rated Load

System experiment parameter: L=1.4mH， C=100μF， output frequency f=50Hz， rated output voltage Uo=220V， and shutoff frequency rate is 20kHz. Figure 6 id the output voltage waveform, when the output voltage THD=0.82%. Figure 7 is waveform and harmonic wave analyses of the output voltage and current with rated load, and its output voltage THD=1.080%； the dynamic properties experiment waveform of the inverter is shown in figure 8, which is the output voltage and current waveform with 25A sudden added resistance load. In this figure, the voltage decline is less than 30V, and the voltage change rate △u% is less than 10％.



(100V/div, 20A/div, 5ms/div)

Fig. 8. Output Voltage and Current Waveform with 25A Sudden Added Resistance Load

5. Conclusion

The thesis introduces repetitive control theory, applies it in the design of the inverter, presents a digit control strategy based on the repetitive control inverter, and introduces the design method of the controller in great detail with the help of the experiment system, based on which TMS320LF2407 serves as the rockchip. Thus the full digit experiment system is developed and experiment verification is made, which proves that few steady state errors when voltage is output under various loads and high precision. In the meantime, the system feature fast response, low voltage change rate and excellent sustainability of sine degree of the output voltage when sudden loads are added. The experiment verifies correctness of the design and very good application prospect of the system.

References

[1] Guo Weinong & Chen Jian: Research on the Inverter Digit Dual-loop Control Technique Based on the State Observer, Journal of Zhejiang Water Conservancy and Hydropower College, 22(9) , p.64-68(2002)

[2] Chen Jian: Power Electronics－Power Electronics Transform and Control Technique, Beijing, Higher Education Press(2002)

[3] Li Jingang, Zhong Yanru & Ma Xin "Research on Multiple-control of Mid-frequency Inverter Based on DSP". Power Electronics, 44(1) , p.71-73(2010)

[4] Haithem Abu-Rub: Predictive Current Control of Voltage-Source Inverters , IEEE Trans. On Industrial Electronics, VOL.51, NO.3 , p. 585~593(2004)

[5] Xie Meng, Cai Kun, Sheng Xiaosong, Wang Ping , Li Yao-hua: Output Control and Parallel Ooeration Control of 400Hz Singe- phase Voltage-source Inverter. Proceedings of the CSEE, 26(6) , p.78-82(2006)

[6] Abdel Rahim Naser M, Quaicoe John E:Analysis and Design of a Multiple Feedback Loop Control Strategy for Single-phase Voltage-source UPS Inverters, IEEE Transactions on Power Electronics, 11(4) , p.532-541(1996)